Calibrating Hyper- and Multispectral Imagers at the NASA Ames Airborne Sensor Facility
CalCon 2014

Thunderhead over the Gulf of Mexico from the Enhanced MODIS Airborne Simulator (9/13/2013; Bands 20, 11, 2)

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UCSC
NASA Ames UARC

NASA Airborne Sensor Facility

- Resides at the University-Affiliated Research Center under the NASA Ames Earth Science Division
- Staffed by Univ. of California, Santa Cruz
- Joint funding from the Airborne Science and EOS Programs
- Provides Earth science mission support through:
  - Facility Sensor Operations
  - Instrumentation Development
  - Sensor Maintenance and Calibration
  - Airborne communications systems development (Sensor Web implementation)
  - Data Processing and Archive

NASA's Calibration Laboratories

NASA's centers of expertise in the calibration and characterization of satellite, ground-based, and airborne remote sensing instruments for over two decades.

GSFC Radiometric Calibration Lab

Maintains and develops lab and field instrumentation, NIST calibrated lamp and tunable laser sources, and detectors to calibrate, monitor, and assess the performance of remote sensing instruments from 340nm to 2400nm

·Missions/projects recently and currently supported:

GSFC AERONET
NPP/JPSS OMPS
NPP/JPSS VIIRS
ORCA
CAR
MAS
MASTER
SOLSE
U. of Lille AERONET
RSP
HAMCAM
Pandora network
PSP
NIP
Cloud Scanner
Rainbow Camera
CO_2 Sounder
eMAS
ATLAS
JPSS CERES
LADEE
GCAS
GEO-TASO
DOE ARM NFOV

GSFC Diffuser Calibration Lab

Maintains and develops instrumentation and NIST calibrated reflectance & transmittance artifacts for the measurement of the bidirectional and hemispherical optical scatter of flight and non-flight optics and materials from 230nm to 1700nm

·Missions/projects recently and currently supported:

NPP/JPSS OMPS
NPP/JPSS VIIRS
ORCA
ICESat-2/LRS
CAR
SBUV/2
APS
RSP
JWST

Multi-wall Carbon Nanotubes for instrument stray light suppression

GSFC Radiometric Calibration Development Lab

Maintains and develops lab, field, and airborne instrumentation and employs NIST calibrated lamp and Radiometric Calibration Laboratory laser sources to calibrate UV to near infrared remote sensing instruments from 200nm to 2500 nm

·Missions/projects recently and currently supported:

Earth Venture1/DiscoverAQ/ACAM instrument and Pandora network
NPP/JPSS OMPS
GCAS
GEO-TASO
ESTO/ACT /Advanced Solar Blind detector array development
CAR
GSFC AERONET
OMI
AMES UV sphere calibration
Wallops Ocean Sensor

Ames Airborne Sensor Facility Calibration Lab

Maintains instrumentation and NIST calibrated sources to calibrate airborne imagers and radiometers in the lab and field from 350 nm to 14 microns

·Missions/projects recently and currently supported:

eMAS-MSS
eMAS-HSI
MASTER
RSP
SSFR
4-STAR
AATS-14
CAR
LCROSS
Field Spectroradiometers

All laboratories have participated in cross-calibration campaigns led by the NIST Optical Technology Division

Calibration Procedure for Existing Facility Multispectral Instruments

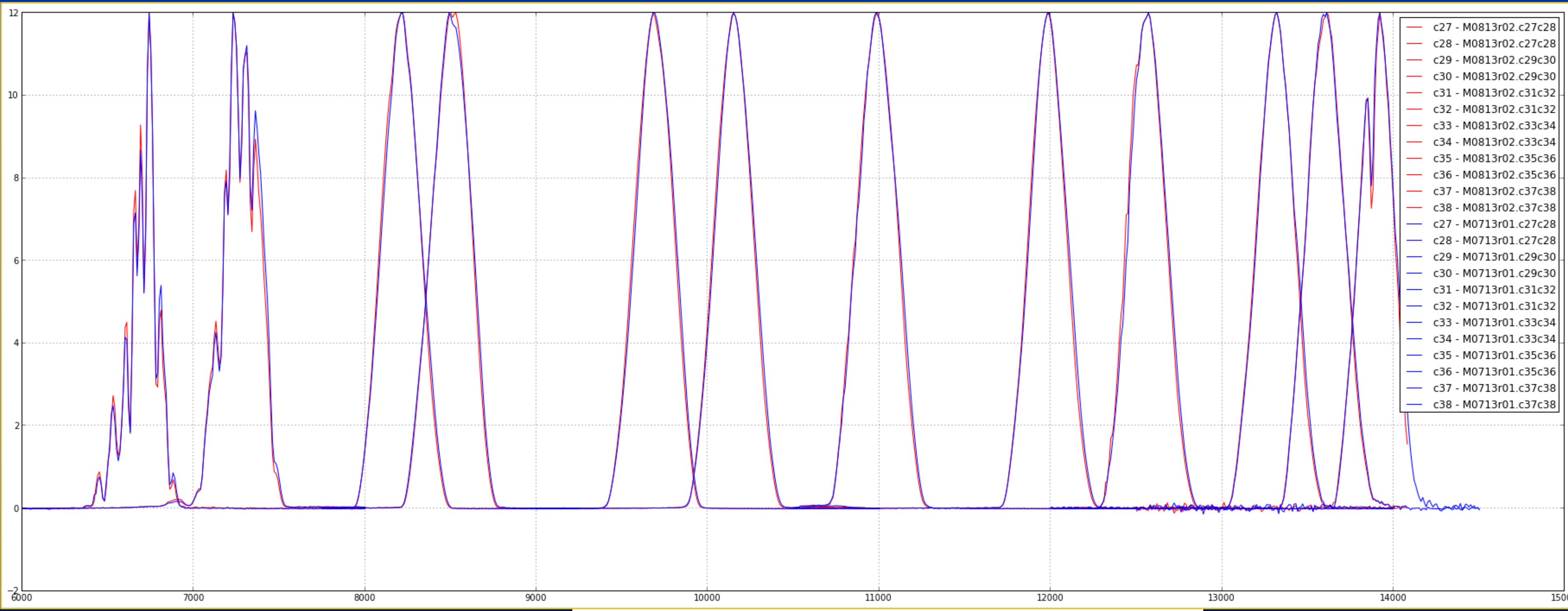
- **Spectral Bench Characterization**
  - Monochromator based Relative Spectral Response (RSR) measurement for all bands

- **Broadband Radiometric Characterization**
  - High output integrating sphere source AKA "HISS" for 350-2500nm spectral bands
  - 12" Extended Area Black Body (LES100-12) for mid-wave IR and thermal IR spectrometer bands

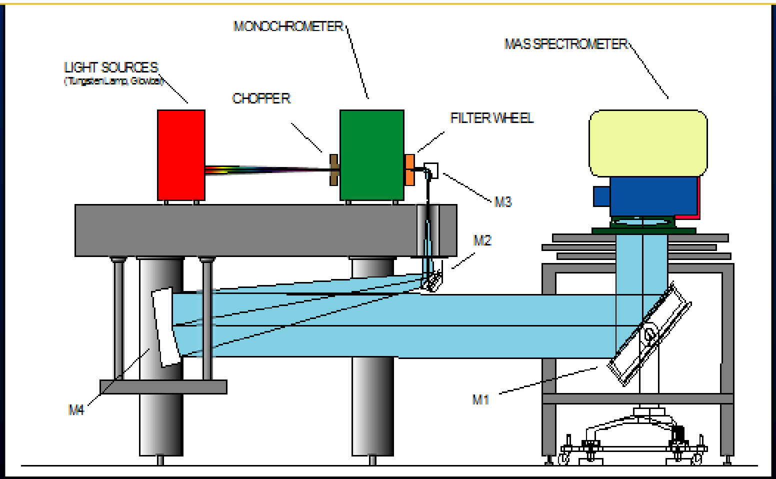
This approach is time tested but not well adapted to new wide field hyperspectral imagers with much higher detector counts.

- Difficult to sample every single detector in wavelength and spatial dimensions for RSR and Radiometric response
- Multispectral cal characterizes one field and all wavelengths.
- Hyperspectral cal must characterize several fields and a fraction of the wavelength bins.

Spectral Bench Characterization
Monochromator based RSR measurement for all bands



Scan mirror parked and IFOV characterized in nadir position



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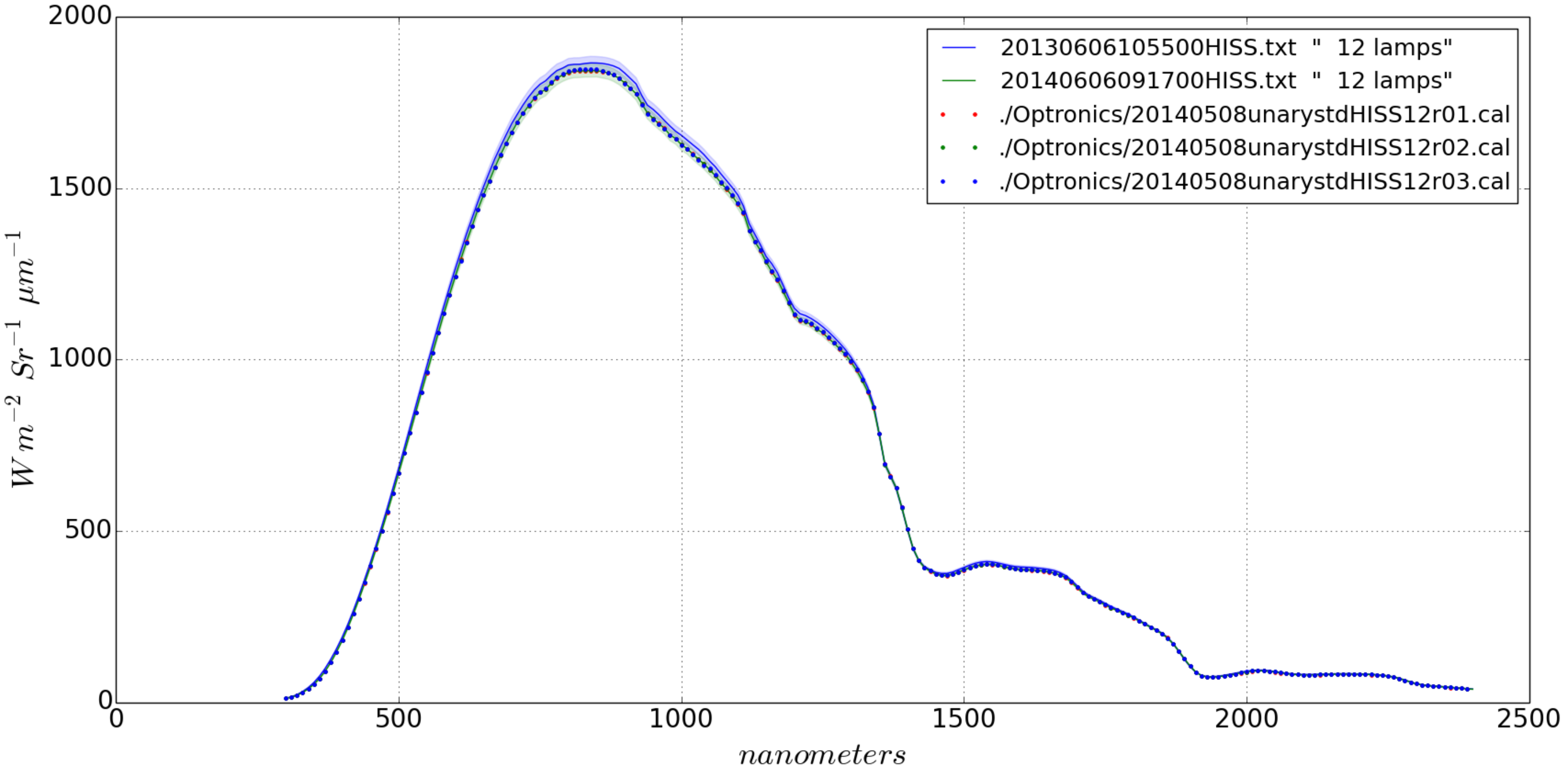
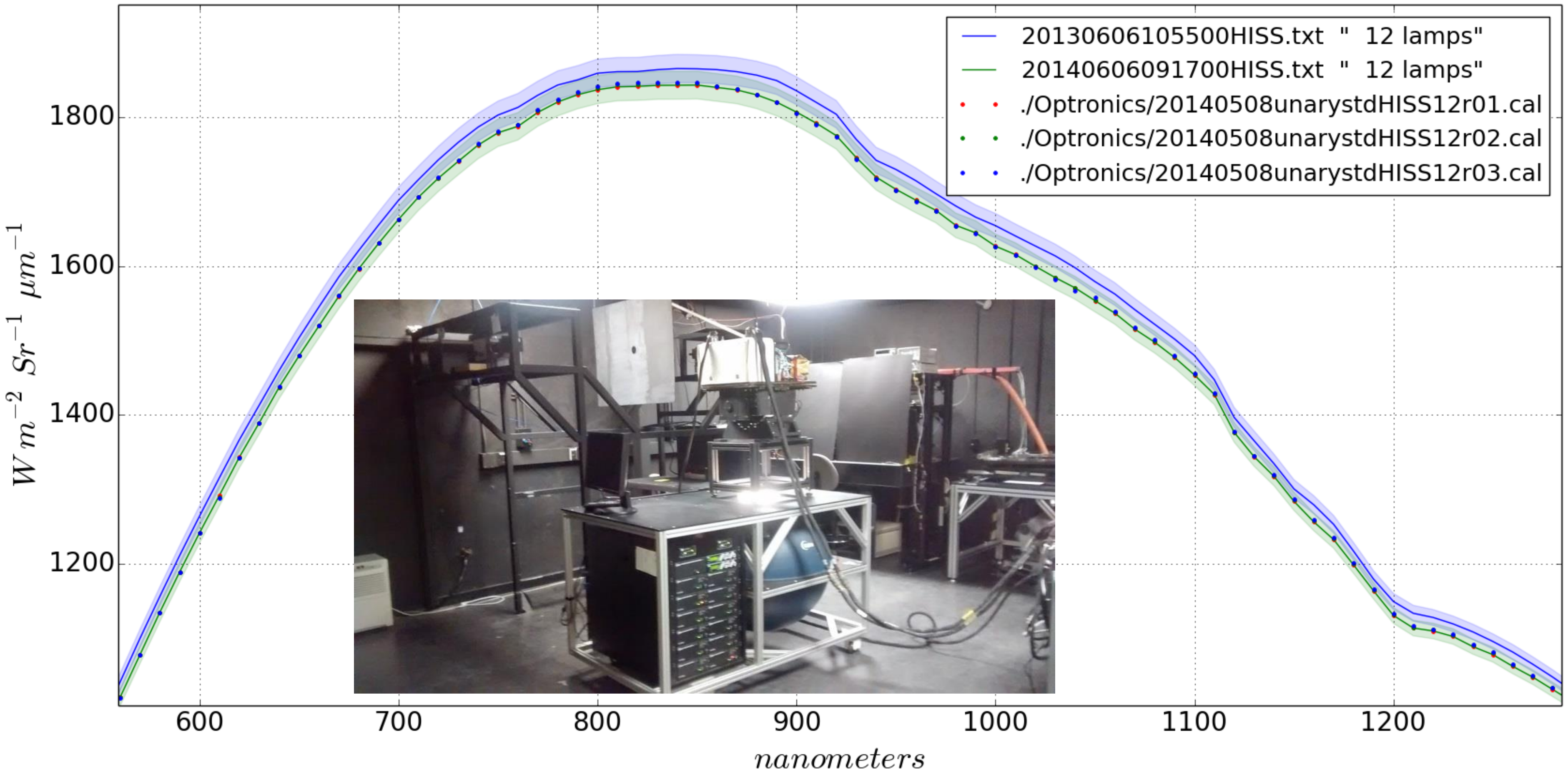
University Affiliated Research Center

Broadband Radiometric Characterization



Broadband Radiometric Characterization

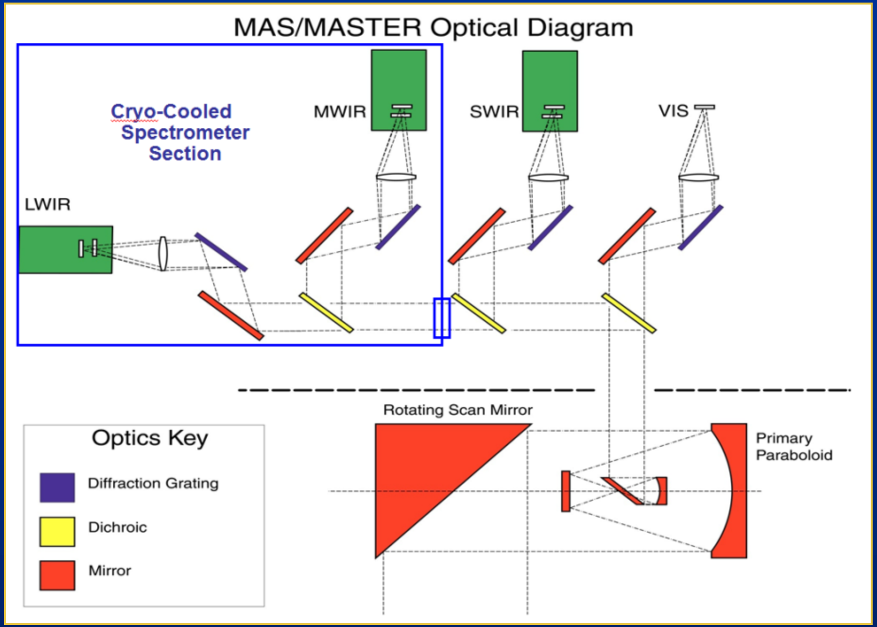


UARC Facility Airborne Instruments

Airborne Scanning Instruments

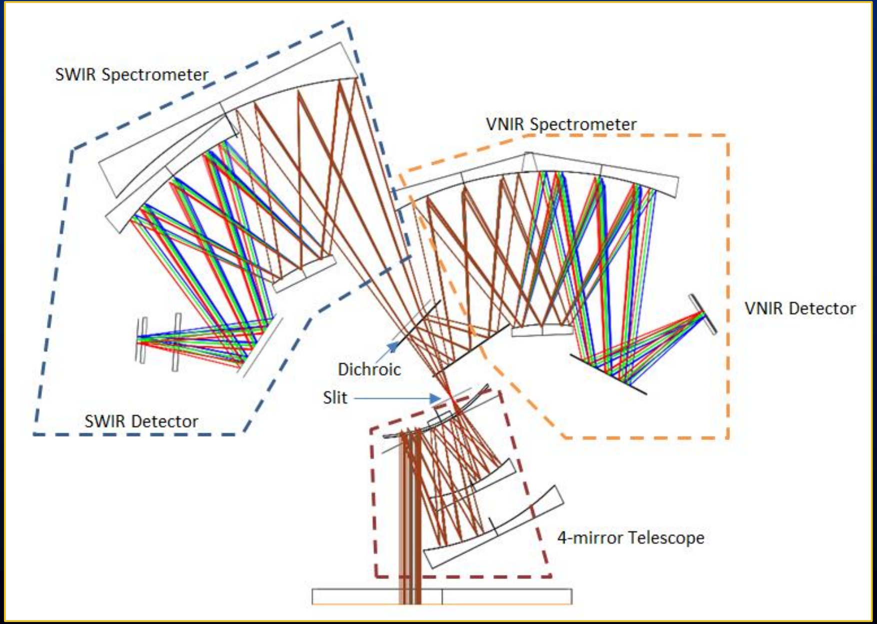
- **eMAS-Multi-Spectral Scanner**
  - Built on the legacy MAS, the MODIS Airborne Simulator
  - In 2010-2012, MAS MWIR and LWIR LN2 dewars were replaced by SDL with a modern Cryocooled optics and FPA package as well as new FPGA Digitizer

- **MASTER**
  - MODIS and ASTER airborne simulator
  - Essentially the same instrument as MAS-classic, sharing the same telescope and scanner mechanism and similar spectrometer and digitizer design but somewhat different spectral band selection



Airborne Hyperspectral Instrument

- **eMAS-hyperspectral**
  - A totally distinct instrument from the legacy MAS/eMAS-MSS, with a confusingly similar name
  - Dual Offner relay spectrometers sharing a single 4 mirror anastigmat telescope



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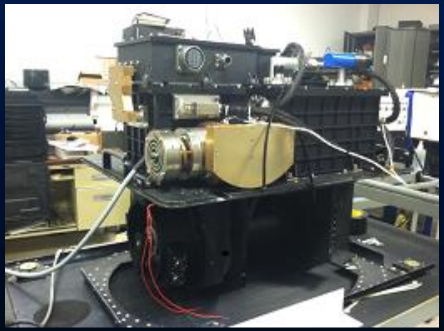
Enhanced MODIS Airborne Simulator

A next-generation airborne imager with high spatial resolution and broad hyper-spectral (VNIR/SWIR) and multi-spectral (MWIR-LWIR) coverage intended to:

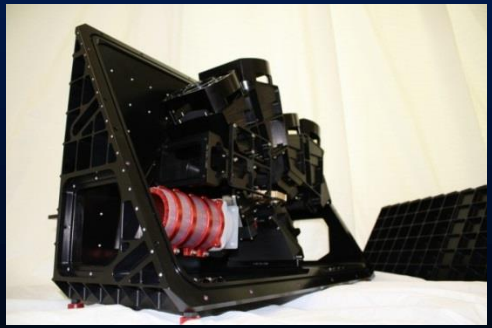
- Simulate existing satellite imager products (MODIS/VIIRS)
- Validate radiances and geophysical retrievals
  (emphasis on cloud and aerosol science)
- Prototype future imager requirements and algorithms (e.g., PACE, ACE)
- Contribute to a wide variety of NASA field studies

Consists of two bore-sighted imaging spectro-radiometers:

- eMAS-MSS: 12 bands 6.7 – 13.9µm, plus 3.7µm (+ 25 legacy MAS V/SWIR bands)
- eMAS-HSI: 205 bands 400 – 2450nm



EMAS-MSS



EMAS-HSI

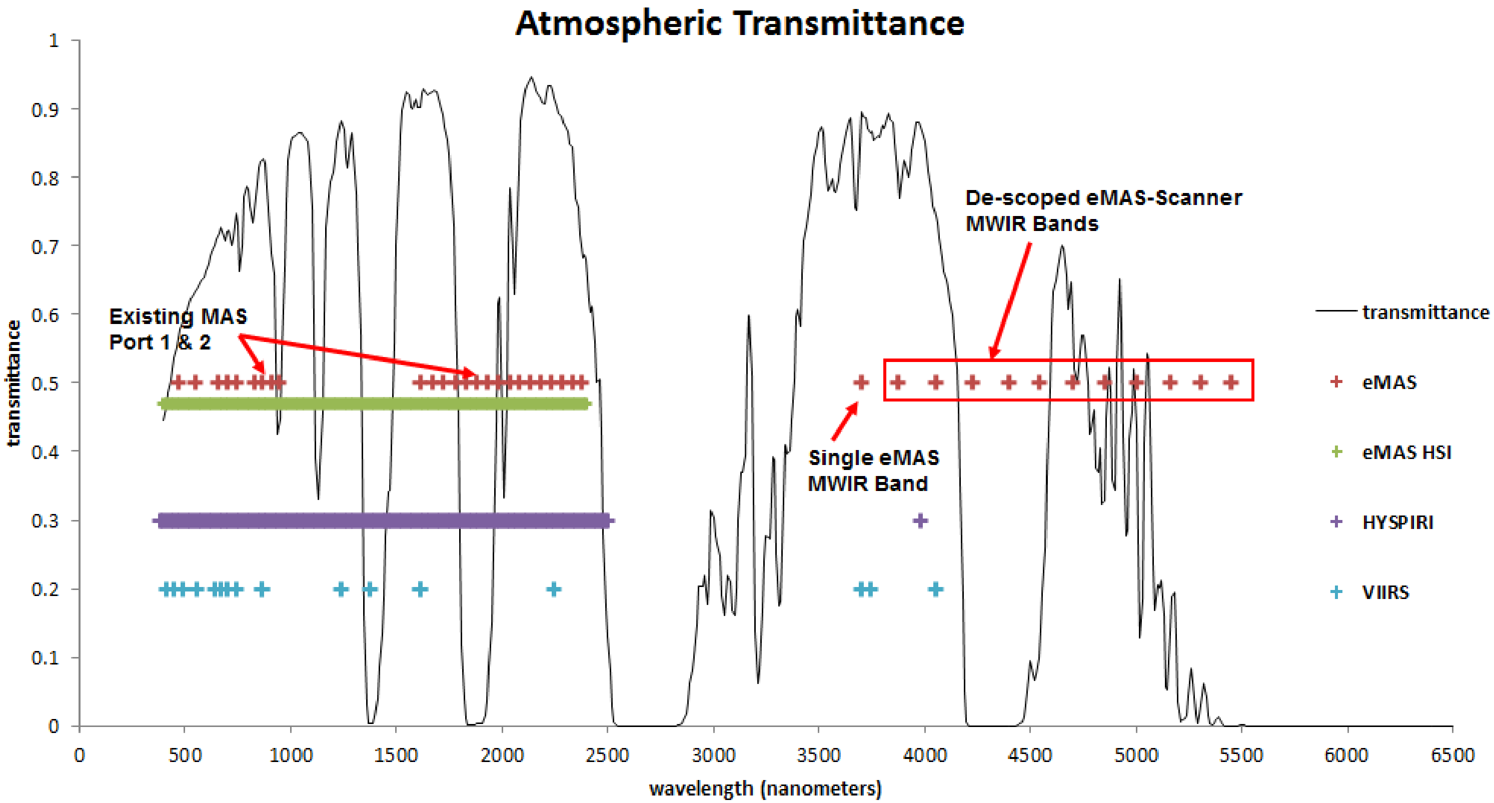
VNIR-MWIR Spectral Coverage

VNIR-MWIR Spectral Band Positions:

eMAS-Scanner and eMAS–HS

HypsIRI

VIIRS



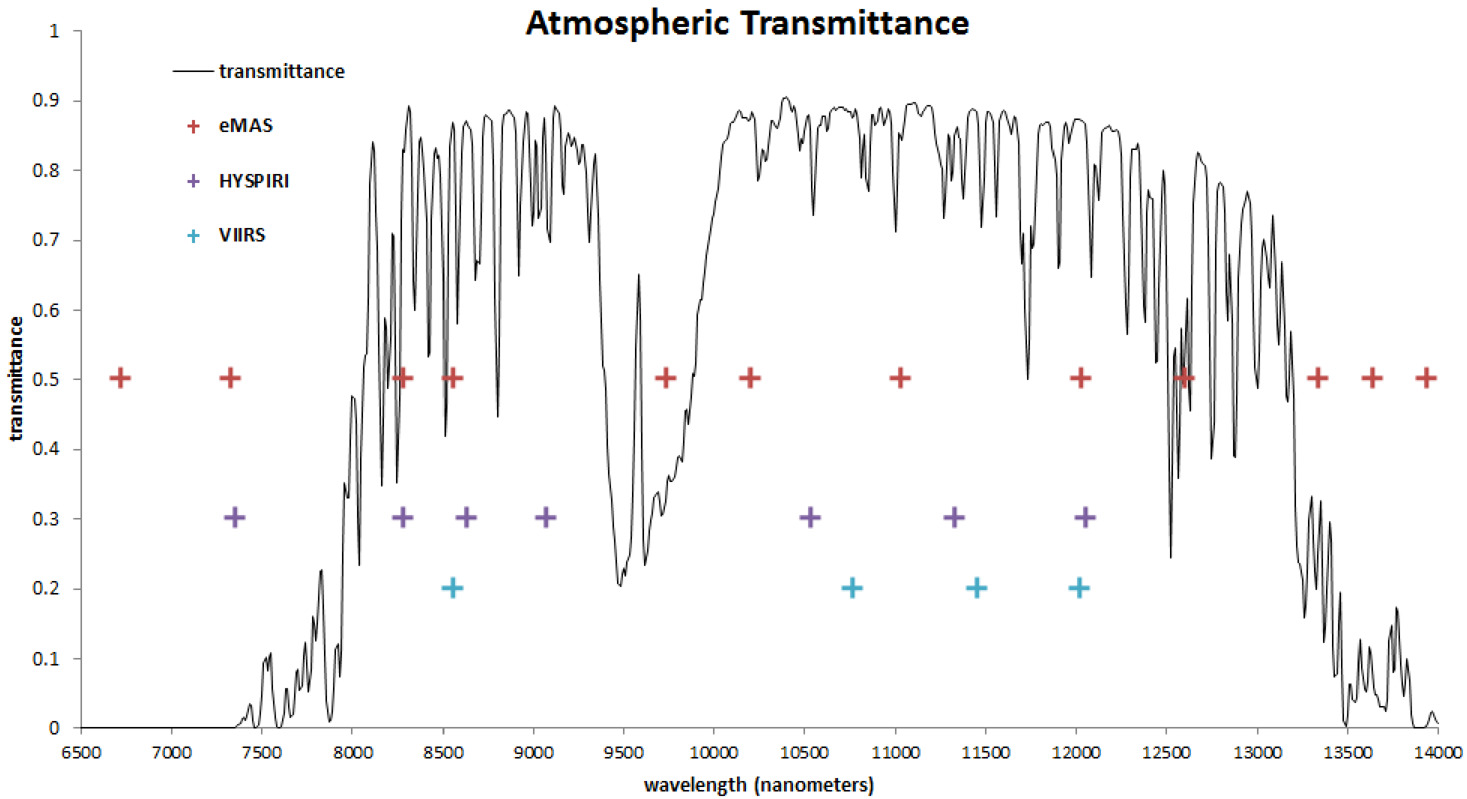
LWIR Spectral Coverage

LWIR Spectral Band Positions:

eMAS-Scanner

HypsIRI

VIIRS



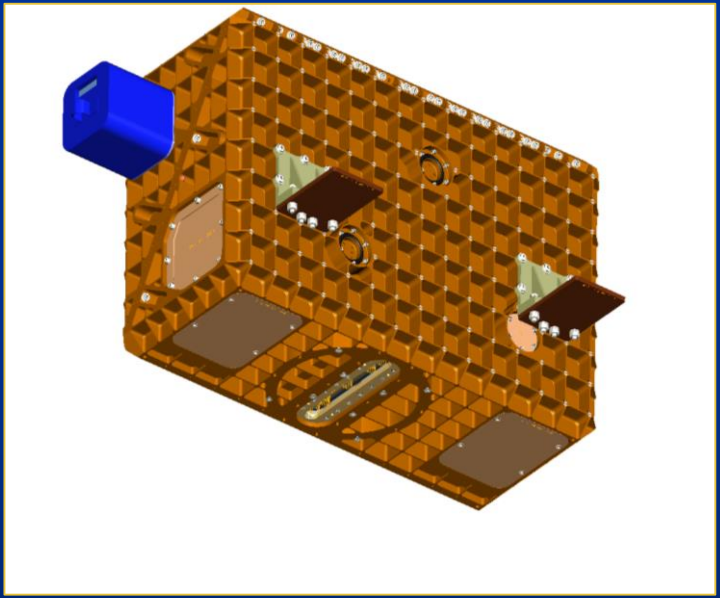
eMAS-scanner and MASTER are essentially similar… but eMAS is *enhanced**.

Instrument:	eMAS-scanner	MASTER
Platform:	NASA ER-2	NASA ER-2, DC-8, & B-200
Ground Speed:	400 Kts (206 M/second)	Variable (depending on altitude)
Altitude:	20 Km (65,000 Ft)	1 - 20 Km (5,000 - 65,000 Ft)
Pixel Spatial Resolution:	50 Meters (@ 20 Km altitude)	5 - 50 Meters (depending on altitude)
Pixels per Scan Line:	716 (roll corrected)	716 (roll corrected)
Scan Rate:	6.25 Hz (scans/second)	6.25, 12.5, & 25 Hz (scans/second)
Swath width:	37.25 Km (22.9 Nm, @ 20 Km altitude)	1.87 - 37.25 Km (depending on altitude)
Field of View:	85.92°	85.92°
Instantaneous Field of View:	2.5 mrad	2.5 mrad
Roll Correction:	+/- 15°	+/- 15°
Data Channels:	38	50
Spectral Bands:	38 (digitized to 16-bit resolution)	50 (digitized to 16-bit resolution)
Port 1 (Vis):	9 bands, 445nm - 967nm	11 bands, 457 - 945nm
Port 2 (SWIR):	16 bands, 1.616µm - 2.425µm	14 bands, 1.609 - 2.394µm
Port 3 (MWIR):	1 band, 3.647µm - 3.830µm	15 bands, 3.148 - 5.263µm
Port 4 (LWIR):	12 bands, 6.589µm - 14.062µm	10 bands, 7.760 - 12.878µm
Bits per Channel:	16	16
Data Rate:	246 Mb/hour	246, 492, & 984 Mb/hour

*new digitizer, mechanically cryocooled thermal IR Spectrometer optics and FPA

eMAS-hyperspectral

- A totally distinct instrument from the legacy MAS/eMAS-scanner
- Dual Offner relay spectrometers sharing a single 4 mirror anastigmat telescope
- 50 degree cross track staring FOV (no scanner)

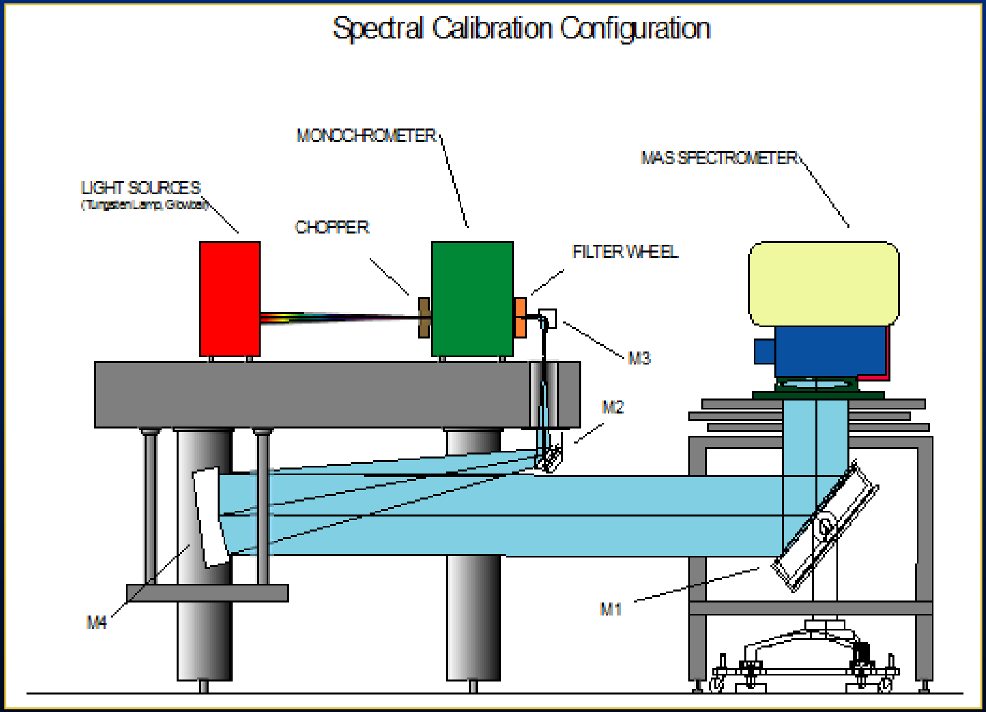


Telescope Parameter	Value
F-number	2.8
Cross-track full field-of-view (deg)	50
Cross-track full field-of-view (rad)	0.873
In-track field-of-view (deg)	0.06
In-track field-of-view (mRad)	1.05
Slit Length (mm)	26.5
Focal Length (Slit Length / FFOV) (mm)	30.4
Focal Length (via. Zemax,off-axis) (mm)	25.6

Spectrometer Parameter	VNIR		SWIR	
	Native	4 x 4 Binning	Native	2 x 1 Binning
Spatial Pixels	2048	512	1000	500
Spectral Pixels	256	64	256	256
Illuminated Spatial Pixels	1656	414	828	414
Illuminated Spectral Bands	254	64	150	150
Pixel Pitch - spatial (mm)	0.016	0.064	0.03	0.06
Pixel Pitch - spectral (mm)	0.016	0.064	0.03	0.03
Spectrometer Magnification	1:01		32:30:00	
Dispersion (nm/mm)	153.8		333	
Spectral Sampling (nm/band)	2.5	10	10	10
IFOV (mRadians)	0.53	2.11	1.05	2.11

Hyperspectral instruments present challenges to the existing lab calibration procedure for multispectral imagers

- **Spectral bench calibration with the monochromator involves parking the scan mirror and characterizing the IFOV with the monochromator source.**
  - **Assumes that the spectral response functions do not depend on scan mirror angle, probably a good assumption* for a scanning instrument.**



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* Notable exception: Polarization of scan mirror vs diffraction grating

Hyperspectral instruments present challenges to the existing calibration procedure for multispectral imagers

- For a wide cross-track field of view instrument with no scan mechanism there is no reason to assume the nadir pixel is representative of all the wider field angle pixels.
  - In fact a better assumption is that the nadir pixel will be the best case pixel.
  - wider field pixels cross track are more likely to suffer more from field aberrations and be lower performing.
  - Furthermore, there are new sources of error to keep track of – two of the principal figures of merit to describe hyperspectral instrument performance are keystone and smile – two aspects of distortion will essentially change the RSR of a given pixel and a function of field angle from nadir.
  - Another FOM is clocking*, this will Cause RSRs to vary linearly with field distance from Nadir and also contribute to cross talk.

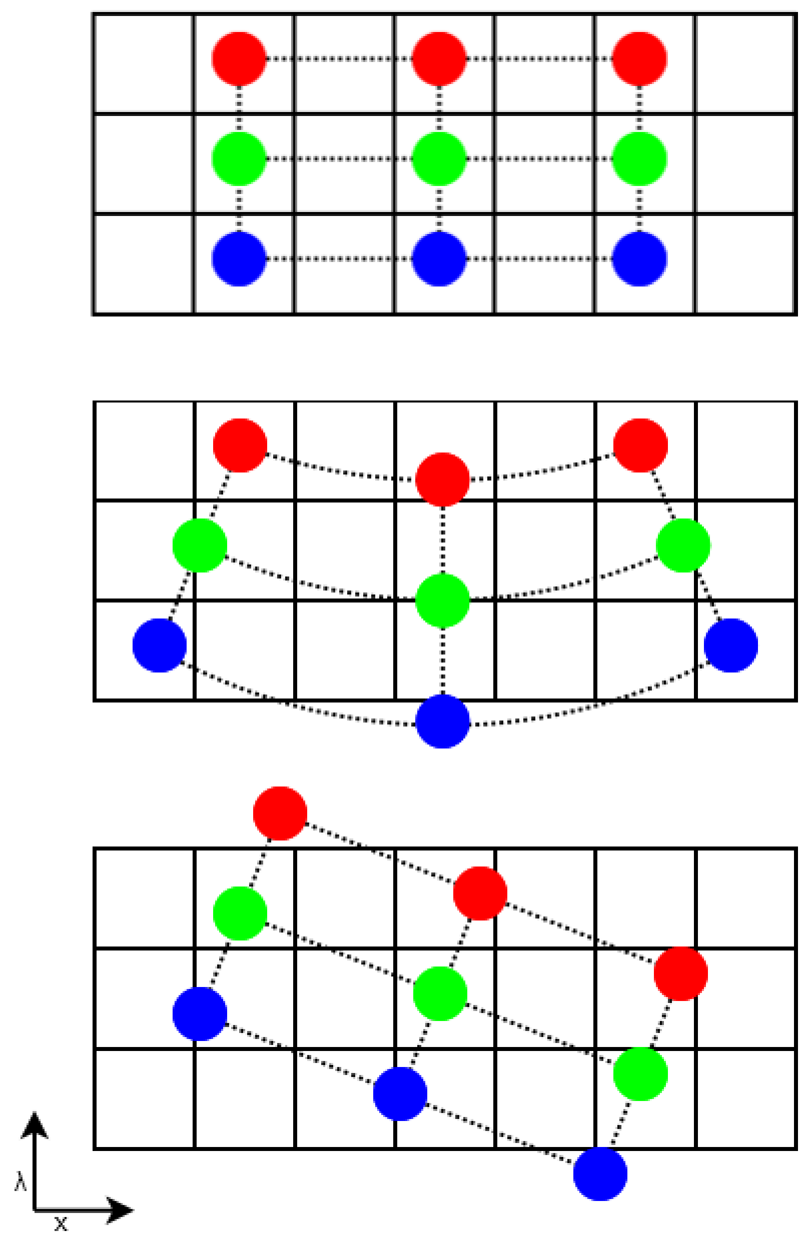
* FPA orientation relative to slit

Visualizing the distortion FOMs

- Clocking
- Keystone
- Smile

- Wouldn't it be nice to probe the wide field pixels as well as nadir?
  - *Solution 1:* rotation stage/goniometer, do each field sample sequentially
  - *Solution 2:* multi-angle pick-off mirrors*, do each field sample simultaneously

* Holly A. Bender ; Pantazis Mouroulis ; Michael L. Eastwood ; Robert O. Green ; Sven Geier ; Eric B. Hochberg; Alignment and characterization of high uniformity imaging spectrometers. Proc. SPIE 8158, Imaging Spectrometry XVI, 81580J



An OAP collimator with a fold.

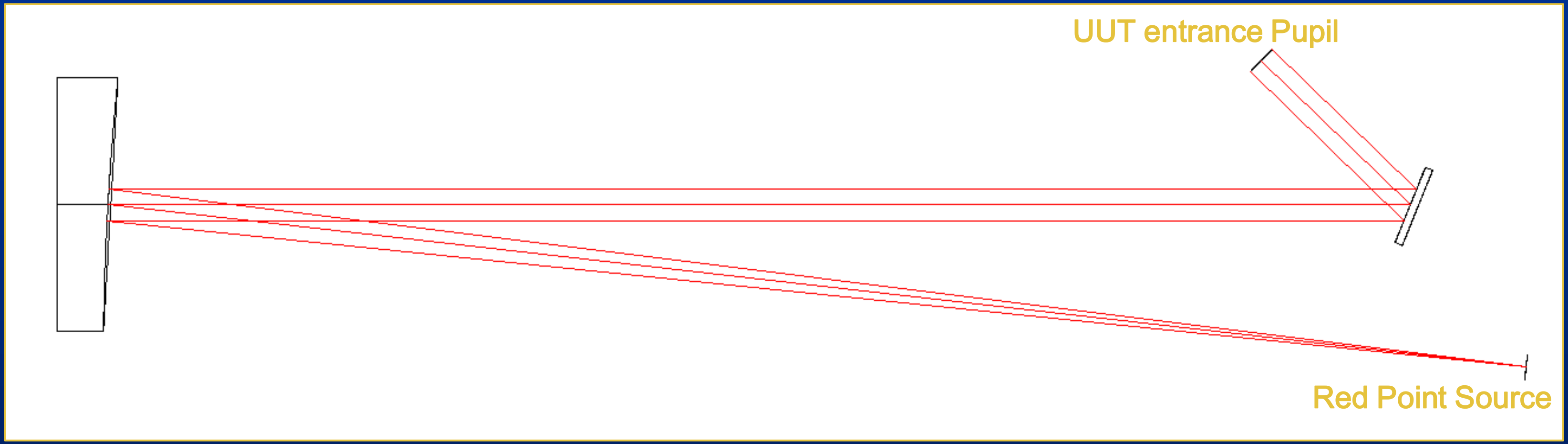
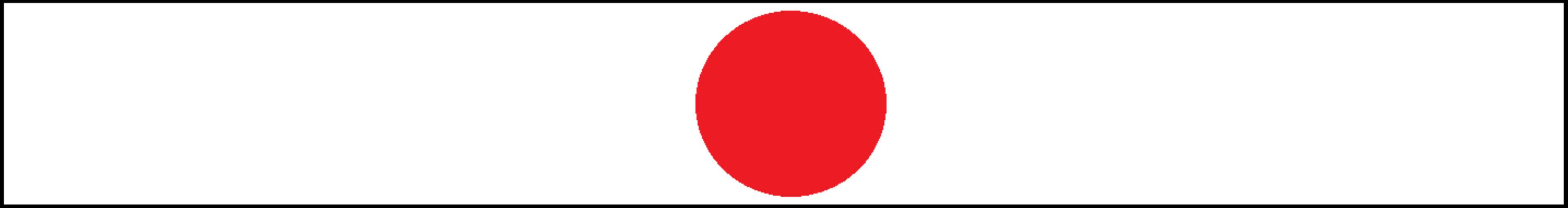


Image at UUT Slit



An OAP collimator with 3 folds.

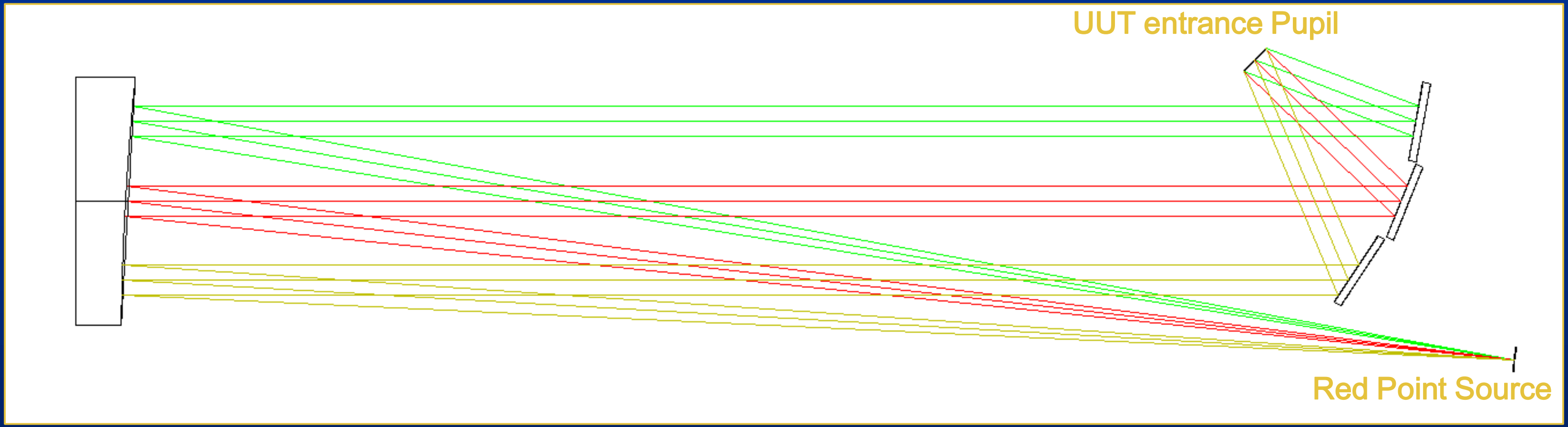
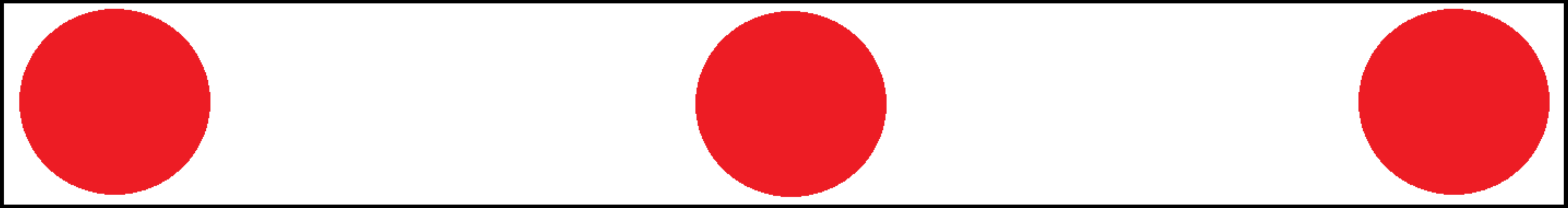
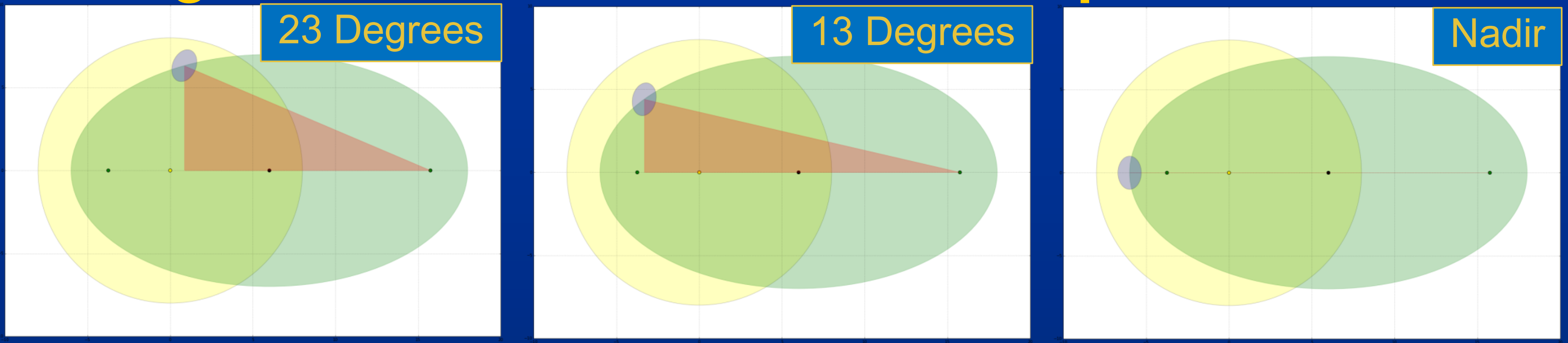
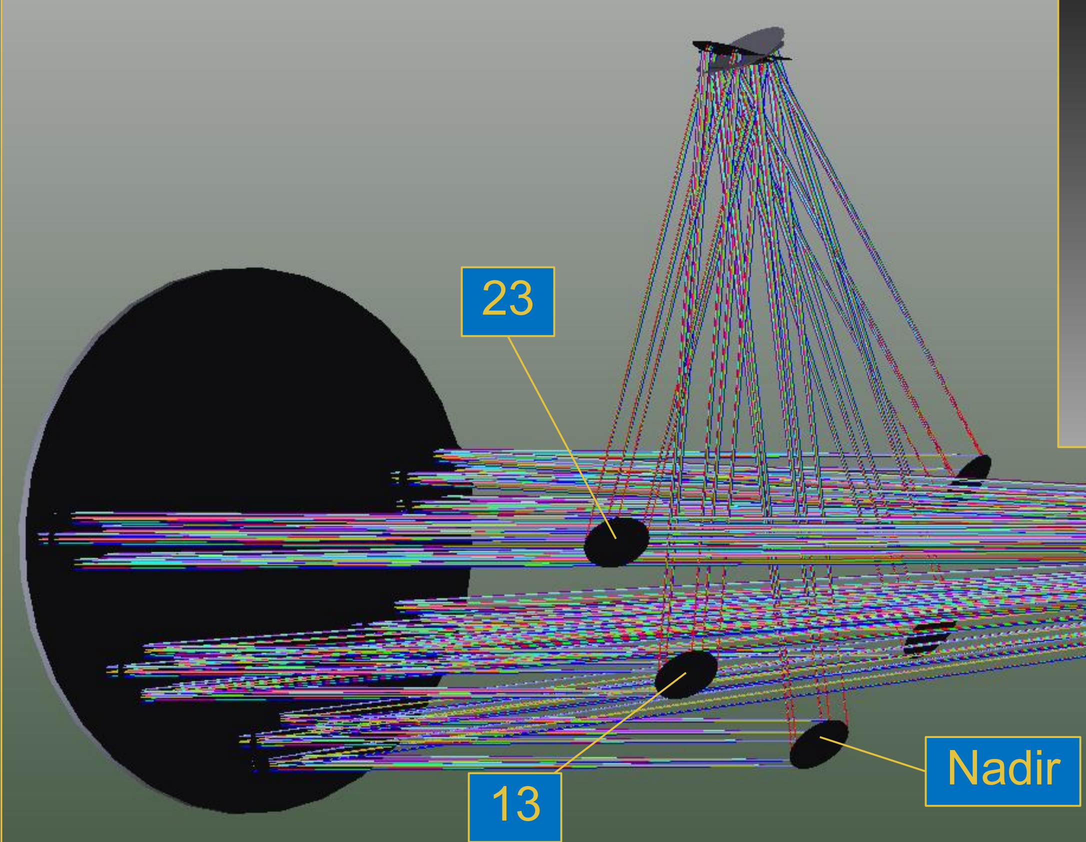


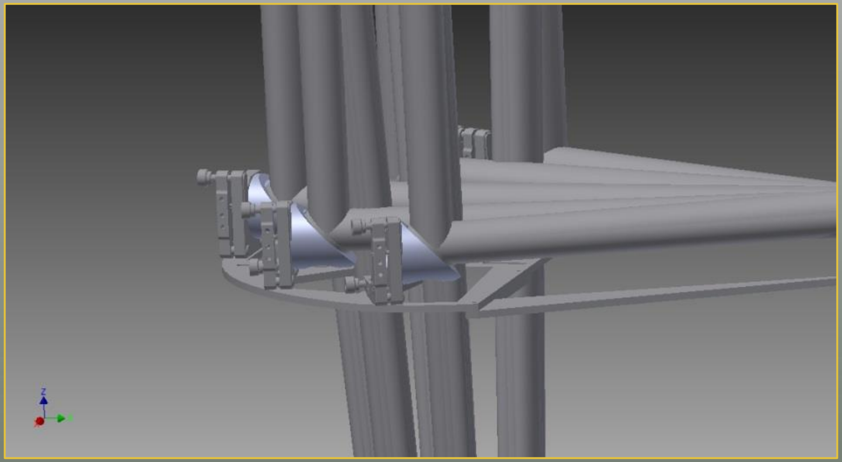
Image at UUT Slit



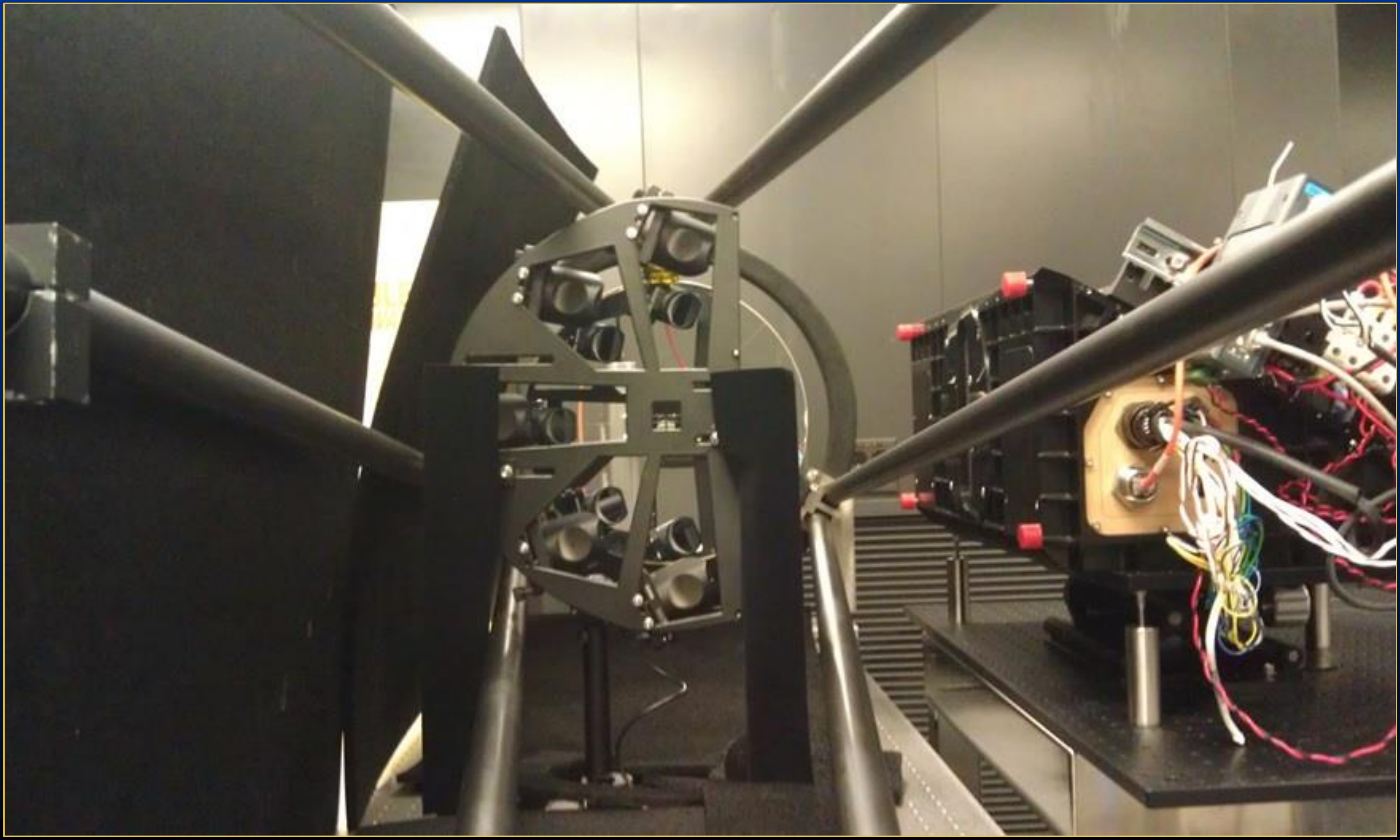
Design for eMAS-h with an on axis parabolic mirror



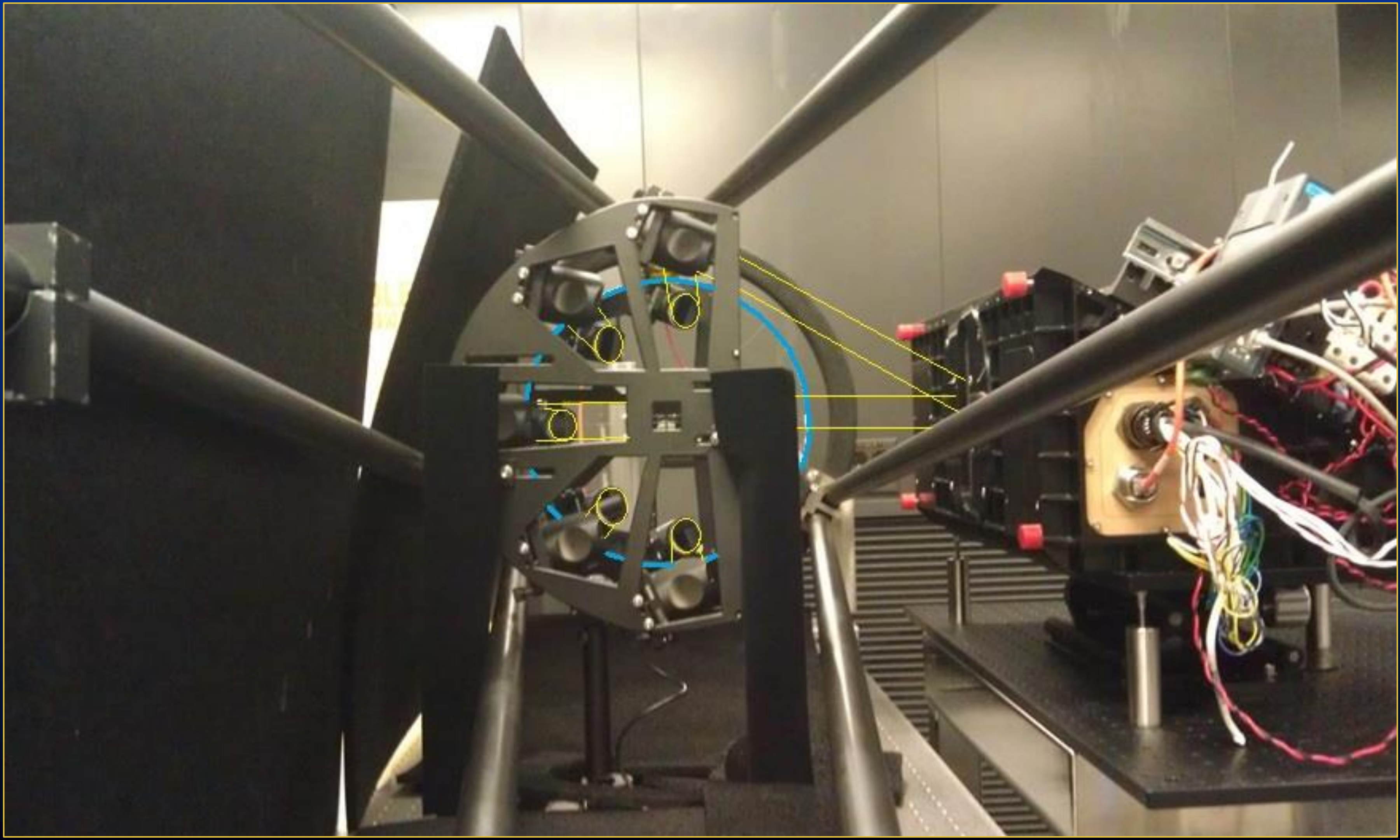




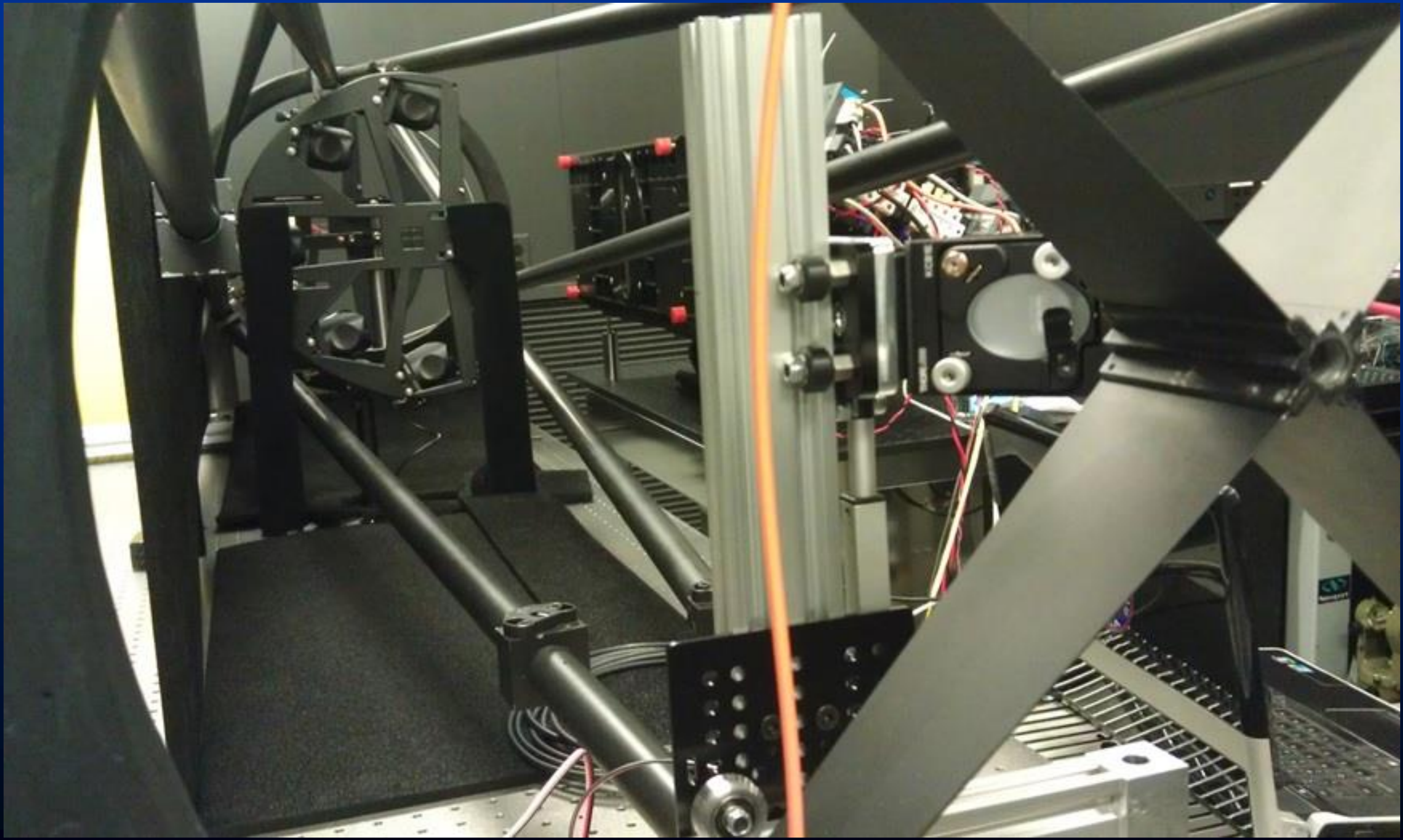
Multi-field Collimator at GSFC Radiometric Cal Lab with on axis parabola - setup



Multi-field Collimator at GSFC Radiometric Cal Lab with on axis parabola - setup



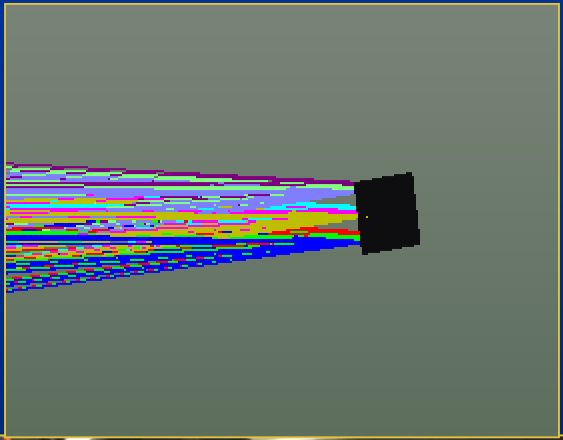
Multi-field Collimator at GSFC Radiometric Cal Lab with on axis parabola -setup

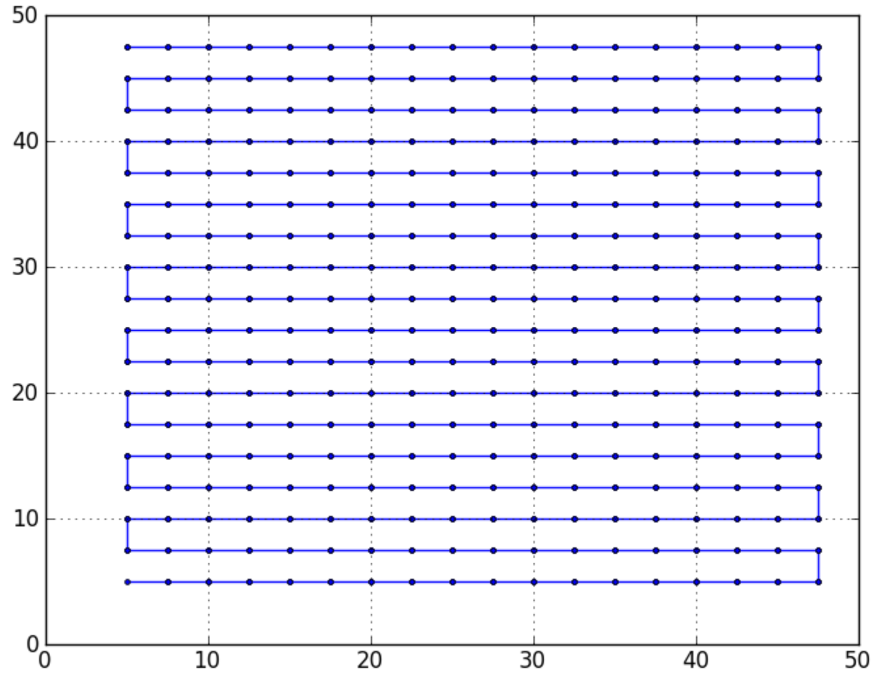


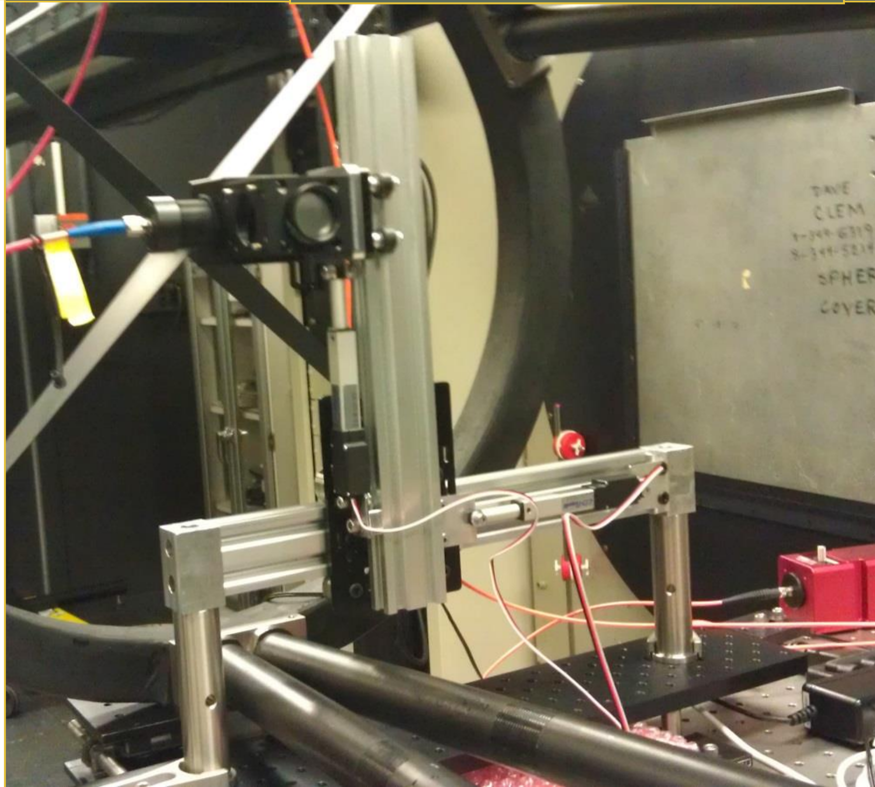
Multi-field Collimator at GSFC Radiometric Cal Lab with On axis parabola

Raster scan at the focus of the parabola to trace out spatial response functions across track and along track

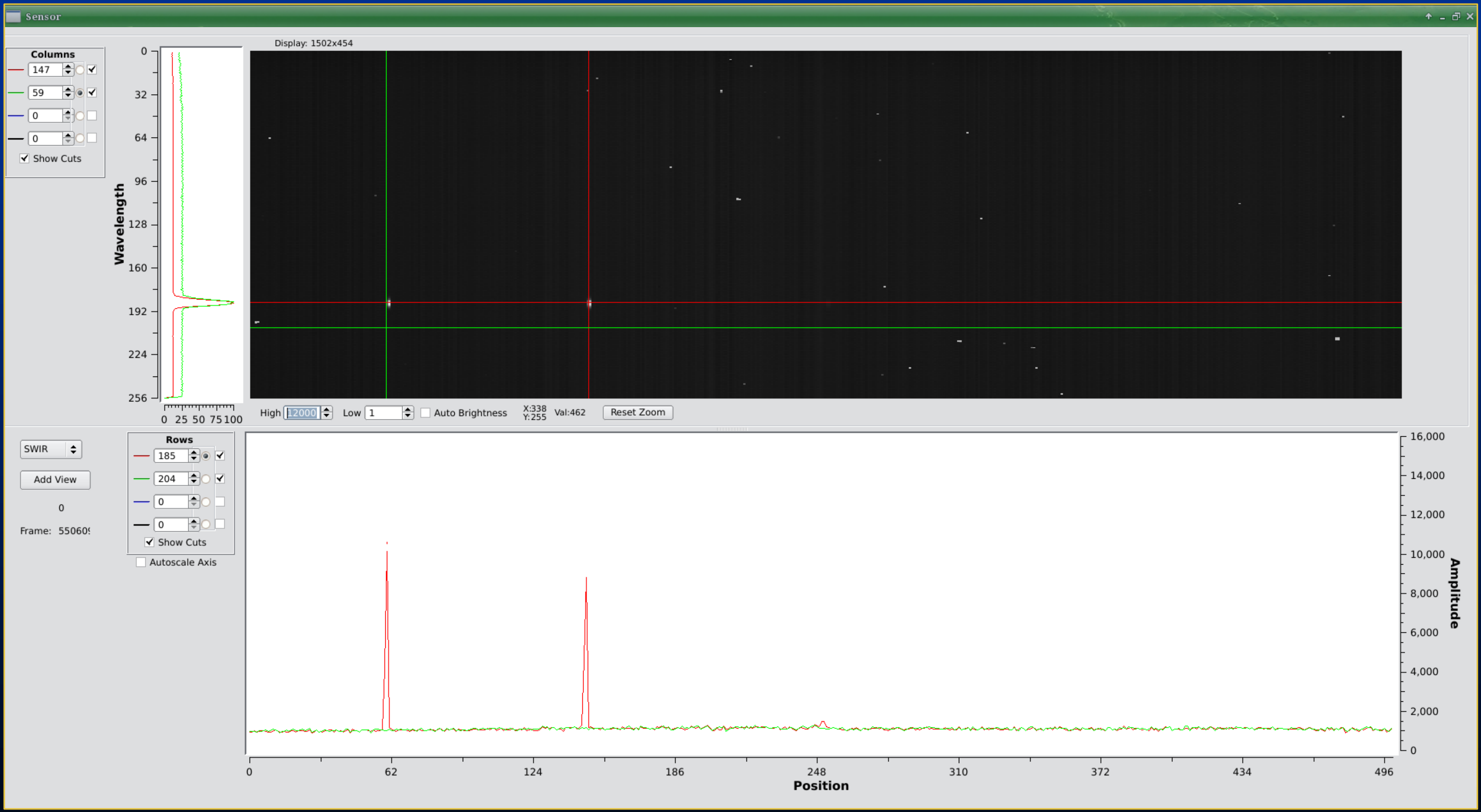
- JPL paper calls these CRF and ARF
- Monday's workshop called it PRF



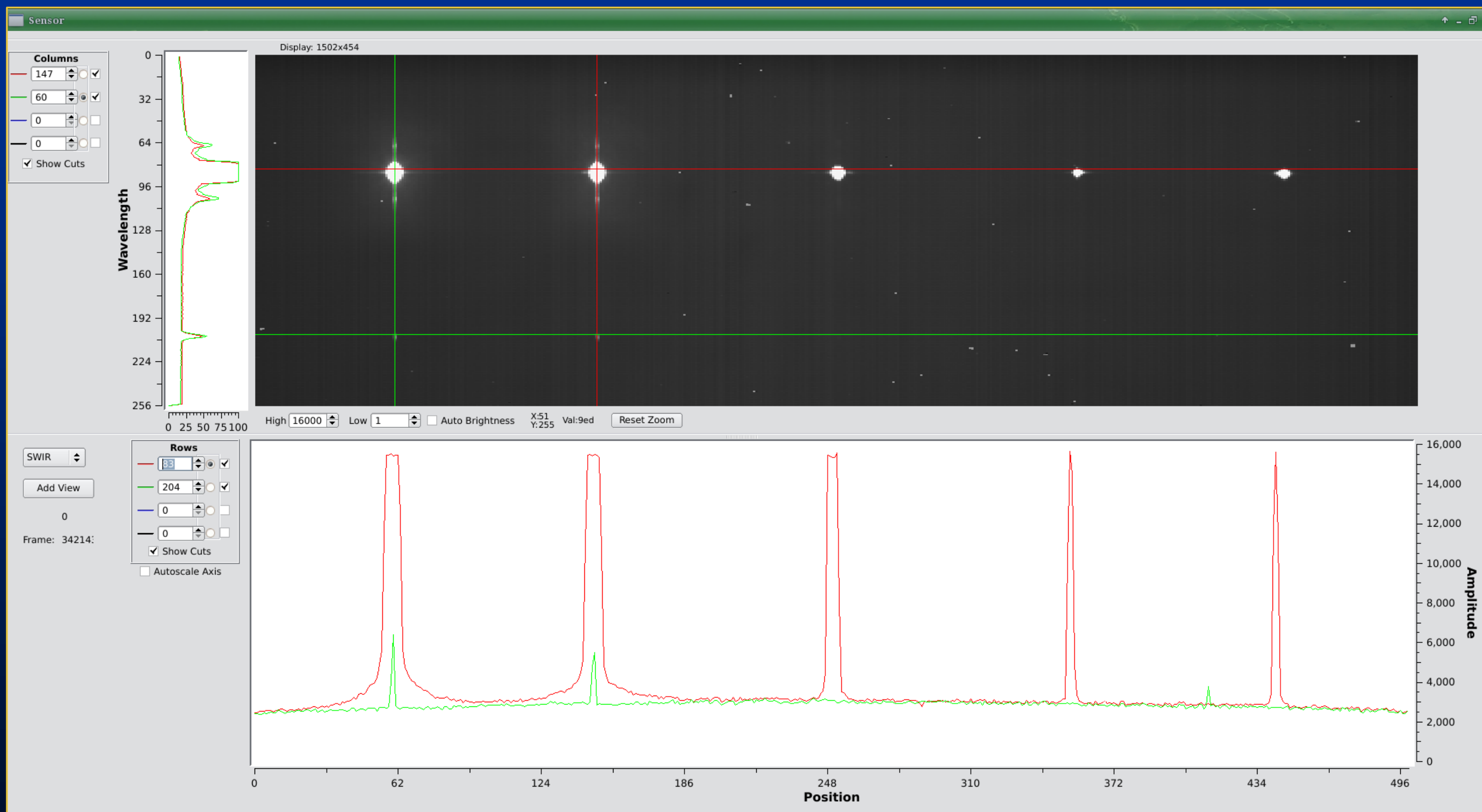




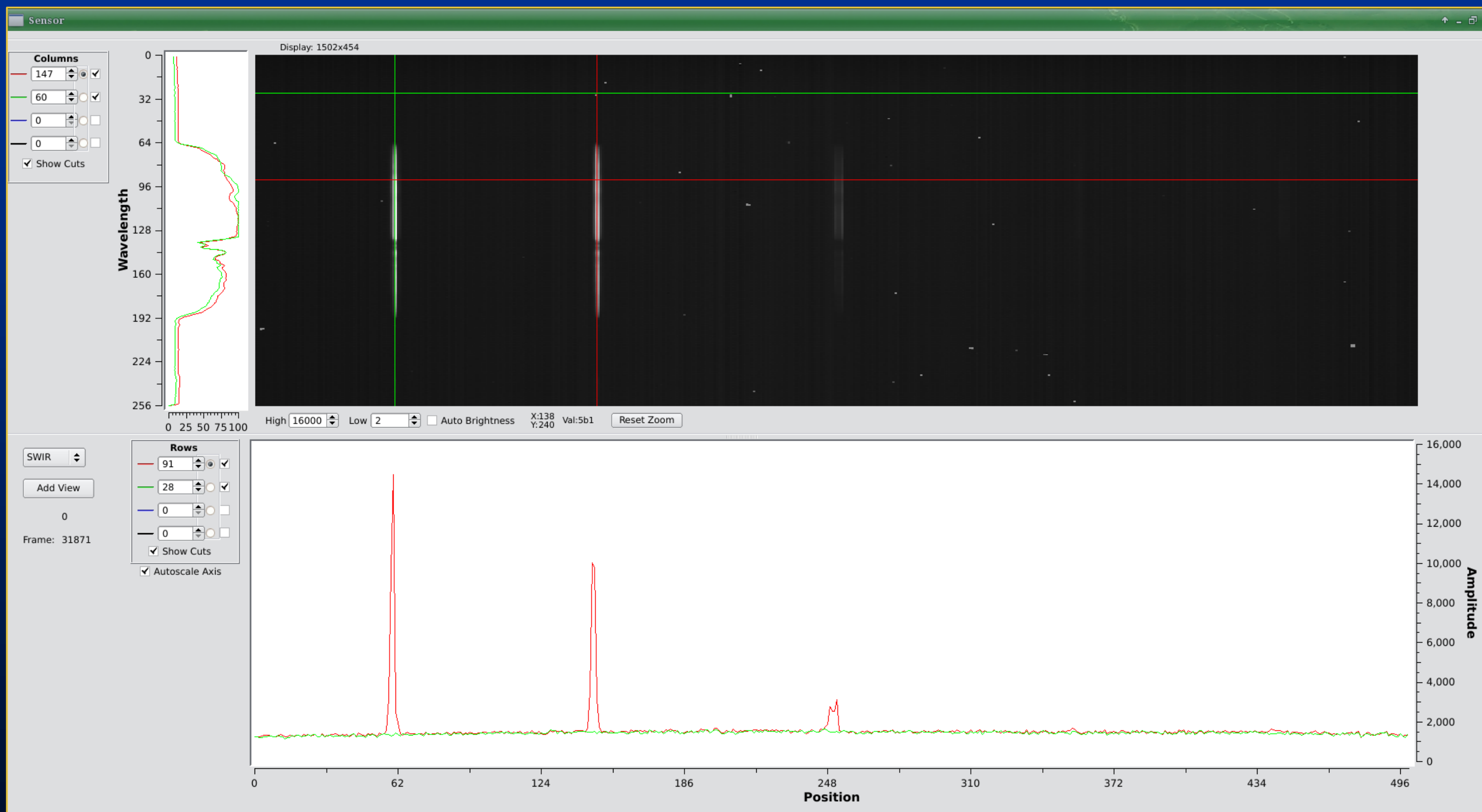
Multi-field Collimator at GSFC SIRCUS with 0n axis parabola – SWIR FPA 2195nm



Multi-field Collimator at GSFC SIRCUS with On axis parabola – SWIR FPA saturated

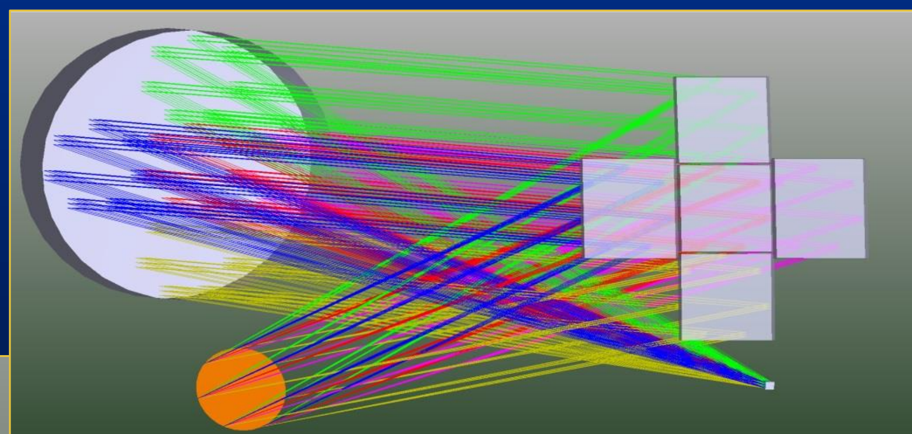


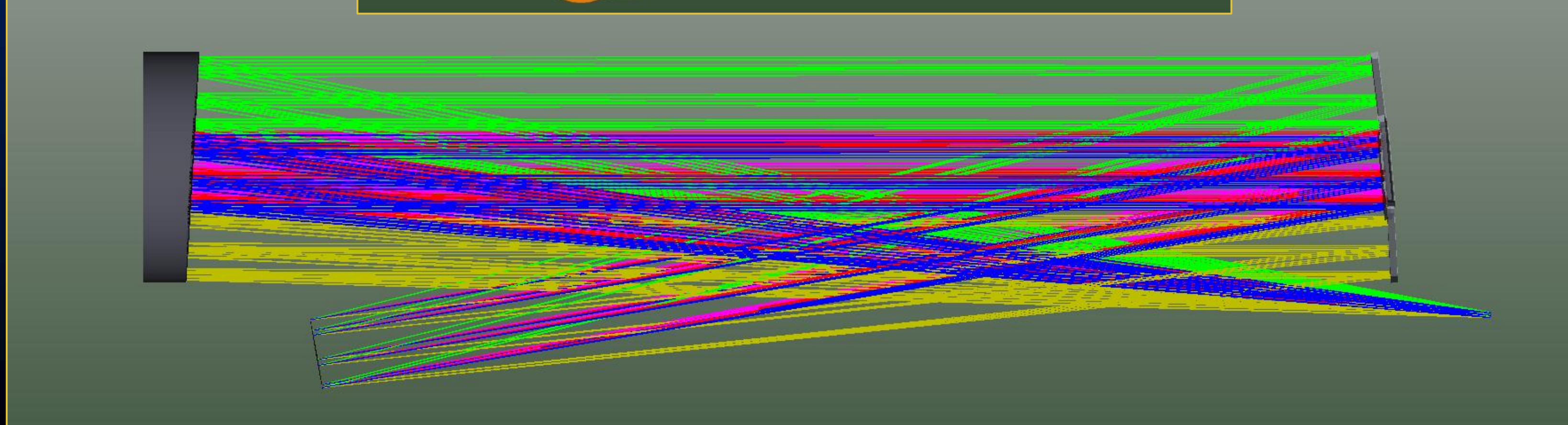
Multi-field Collimator at GSFC with On axis parabola - SWIR FPA white light



Concept is flexible enough to support either wide field with small aperture or large aperture with less wide field

- **Assuming a 16” OAP it is possible to design for staring systems with 12mm Aperture & 50 degree field of view (e.g., eMAS-h) and seven field positions.**
- **It’s also possible to change the pickoff mirrors to support three field locations for an aperture 125mm and cross track FOV of 10 degrees.**
- **Polarization filters in each field angle to study polarization vs field?**
- **HIP as a source instead of mechanically scanned point source?**





Reference Websites

- **General Information & Flight Requests**
  - http://airbornescience.nasa.gov

- **MASTER web page**
  - http://masterweb.jpl.nasa.gov

- **MAS web page**
  - http://mas.arc.nasa.gov

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